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GOLD AND TELLURIDE MINERALIZATION AT THE GOLDLUND MINE, NORTHWESTERN ONTARIO. I. ORE MINERALOGY

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ABSTRACT

Native gold and the Au–Ag tellurides calaverite and petzite occur at the Goldlund mine, northwestern Ontario. Economic concentrations are found in fracture-filling quartz veins and associated zones of alteration in an albitized tonalite host-rock. Mineralization occurred in a three-stage sequence. Minerals deposited during the first stage include pyrite, scheelite, xenotime and secondary magnetite and ilmenite. In the intermediate stage, sphalerite, chalcopyrite, galena and a second generation of pyrite were deposited. In the final stage, gold and the tellurides were formed. Textural relationships suggest that pyrite played an important role in gold mineralization. Gold and the tellurides crystallized simultaneously with the second generation of pyrite, and occur as exsolution phases in pyrite. The contact of gold-bearing fluids with both generations of pyrite appears to have resulted in the continued precipitation of gold. The intimate association of calaverite, petzite and a gold-rich alloy of composition $Au_{88}Ag_{12}$ to $Au_{97}Ag_3$ (atom %) suggests a temperature of formation of approximately 300°C for the late stage of mineralization.

Keywords: late-stage gold mineralization, calaverite, petzite, native gold, exsolution, Goldlund mine, Ontario.

SOMMAIRE

On trouve de l'or natif et les tellurures Au–Ag calavérite et petzite à la mine Goldlund, dans le nord-ouest de l'Ontario. Les concentrations économiques d'or se trouvent dans les veines de quartz qui occupent les fissures et dans les zones d'altération de la roche hôte, une tonalite albitisée, qui leur sont associées. On reconnaît trois stades de minéralization. Pyrite, scheelite, xénotime, magnétite secondaire et ilménite caractérisent le premier stade. Sphalérite, chalcopyrite et une deuxième génération de pyrite ont été déposées au stade intermédiaire. Au stade final sont apparus: or natif, calavérite, petzite et altaïte. Les relations texturales font penser que la pyrite a joué un rôle important dans la minéralisation de l'or. L'or natif et les tellurures ont cristallisé en même temps que la deuxième génération de pyrite, et constituent des phases d'exsolution dans la pyrite. Au contact avec une phase fluide, les deux générations de pyrite semblent avoir dégagé de l'or. L'association intime de calavérite, petzite, et un alliage riche en or, de composition $Au_{88}Ag_{12}$ à $Au_{97}Ag_3$ (proportions atomiques) indiquerait une température approximative de déposition de l'assemblage tardif de 300°C.

(Traduit par la Rédaction)

Mots-clés: minéralisation tardive de l'or, calavérite, petzite, or natif, exsolution, mine Goldlund, Ontario.

INTRODUCTION

The Goldlund gold mine, operated from 1940 to 1985, is located 45 km southwest of Sioux Lookout, Ontario, in the Wabigoon Subprovince of the Superior Province. The dominant rock-types in the mine area are Archean felsic to mafic metavolcanic rocks of the Central Volcanic Belt. Numerous Algoman intrusive bodies cut the belt, most notably albitized tonalite dykes in the mine area and the Crossecho Stock a few km to the west. The setting of the deposit has been discussed in detail by Webb (1948), Page (1984) and Chorlton (1986). Gold occurs in cross-cutting veins and associated zones of alteration within the albitized tonalite dykes. Most of the gold occurs in a dyke 10 to 50 m wide that constitutes ore zone #1.

Samples showing detailed mineral-to-mineral relationships were collected from the open pit and stopes 1-27E, 1-13E and 1-11E within ore zone #1. The veins are fracture fillings of quartz with lesser amounts of ankerite, calcite, ilmenite, pyrite and other sulfides. The dykes have been visibly altered adjacent to the veins; carbonatization, albitization and pyritization are the major types of alteration.

Gold mineralization of Goldlund occurred in a late-stage event that involved precipitation of Au–Ag tellurides and native gold. Tellurides are important in a variety of gold deposits around the world, most notably some of those in western Australia, Colorado, Ontario, and Japan (Markham 1960, Kelly & Goddard 1969, Thompson 1949, Boyle 1979). Krennerite, calaverite, sylvanite, nagyagite, muthmannite, and petzite are the most common Au–Ag tellurides reported in the Ontario deposits (Boyle 1979). At Goldlund, however, only petzite and calaverite have been identified. The gold mineralization at Goldlund is similar to that of the Oriental mine, California, but the host rock there is an auriferous granite (Coveney 1981). Both the mineralization and the alteration at Goldlund are similar to those of the Sigma mine in Quebec, where gold mineralization occurs in deformed andesitic flows, porphyritic diorite bodies, and feldspar porphyry dykes (Robert & Brown 1986).

Analytical Techniques

Polished thin sections of the high-grade ore were examined using both a polarizing-light microscope and a scanning-electron microscope - electron-probe microanalyzer (SEM–EPMA). Back-scattered electron imagery was used to examine the complex relationships among the sulfides, oxides, tellurides and native gold. Mineral analyses were performed on polished thin sections using a JEOL 35C SEM–EPMA, equipped with a KEVEX energy-dispersion solid-state detector. The system was operated at an accelerating voltage of 15 kV and a beam current of 935 pA. All of the analyses were performed using a 200-second counting time. The X-ray spectra were regressed using the Tracor Northern XML and ZAF programs. Natural and synthetic materials from the Natural Materials Analytical Laboratory at the University of North Dakota were used as standards (synthetic krennerite and calaverite, natural chalcopyrite and Au, Ag, Te, Pb, Cu, Co, Zn, Ni and Fe metals).

Analysis of multiple reference and standard materials suggests that the accuracy in results of major-element analyses is on the order of ± 2% of the amount present. Minor elements (Fe, Zn, Cu, Co, Ni, S) were detected at concentrations less than 0.3 wt.%, but these results are not reported here because of the large and unknown uncertainties associated with them.

Ore Mineralogy

Mineralization at Goldlund occurred in three distinct stages (Fig. 1). These stages can be identified on the basis of textural relationships among the various minerals. The first-stage minerals were deposited mainly in altered zones of the host rock, with the exception of ilmenite, which was deposited in veins adjacent to the main fracture. Continued influx of ore-bearing fluids resulted in the deposition of intermediate-stage minerals in both veins and associated zones of alteration. The breakdown of magnetite and ilmenite in the host rock resulted in the formation of ankerite and rutile. Some replacement of first-stage minerals by those of the intermediate stage occurred. Minerals of the late gold-

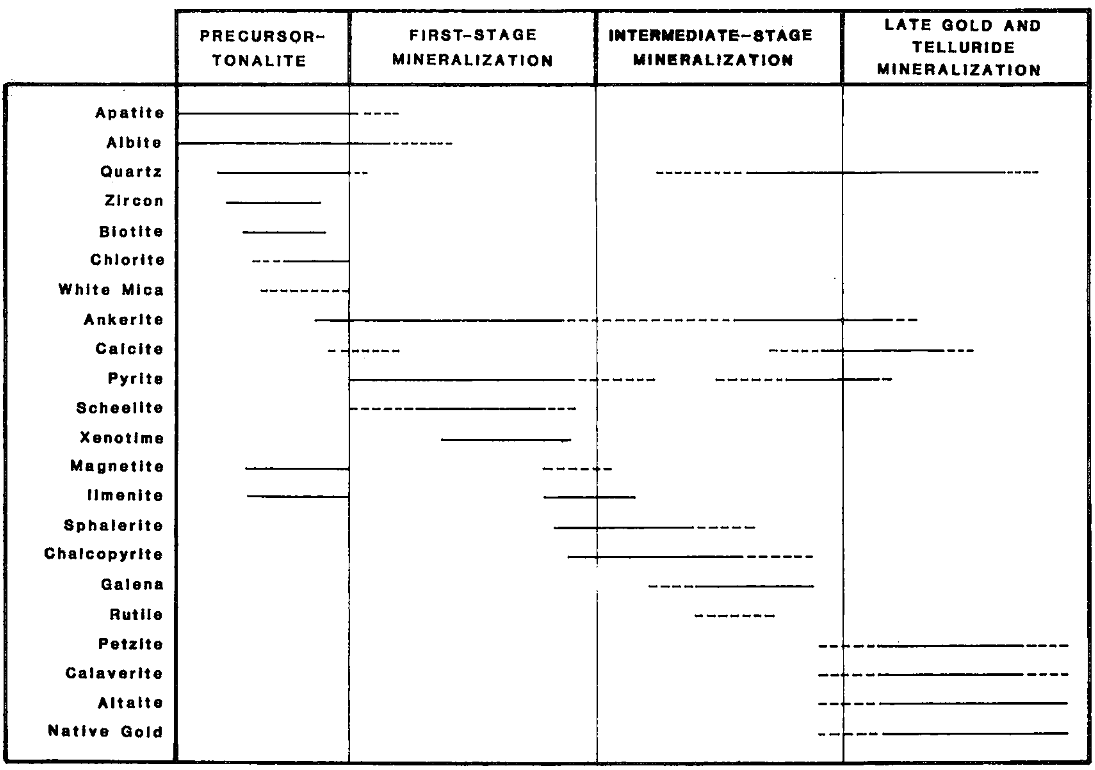

FIG. 1. Generalized paragenetic sequence for minerals at the Goldlund mine. Dashed lines represent uncertainties.

and telluride-stage commonly replace, or occur in veins within, minerals of the previous stages of mineralization.

First-stage mineralization

The highest-temperature stage of mineralization resulted in the formation of pyrite, scheelite, xenotime and secondary magnetite and ilmenite. The pyrite that formed at this stage consists of fine-grained aggregates and individual grains. The anhedral pyrite is disseminated throughout the altered zones of the host rock and occasionally in the unaltered host-rock.

Although scheelite at the Goldlund deposit was reported to be common by Blackburn & Janes (1983), only minor amounts were observed in the present study. In the altered zones, 20- to 60-μm, subhedral to anhedral grains of scheelite are found in contact with ilmenite, rutile, xenotime and gangue minerals (Fig. 2) and, occasionally, pyrite. No scheelite is found in the unaltered host-rock.

Euhedral to anhedral grains of xenotime, 1 to 50 μm across, are present in minor amounts in some of the gold-bearing sections. Xenotime occurs in direct contact with many minerals in the altered zones, including: rutile, ilmenite, apatite, scheelite, monazite, altaite and pyrite.

The scarcity of magnetite in the altered host-rock and geochemical evidence of depletion of iron in the zones of alteration are interpreted, in part, as being caused by the breakdown of iron silicates and primary magnetite (Giddings 1986). Where present in the altered zones, magnetite occurs as small anhedral grains or aggregates commonly associated with ilmenite; it locally embays and replaces first-generation pyrite.

Ilmenite, which is commonly associated with rutile, occurs as irregular grains interstitial to gangue minerals of the albitized tonalite, sheet-like grains concentrated along the outside of the vein walls with ankerite and calcite, and with rutile in complex grains. Ilmenite is also found to embay a 30-μm rounded grain of scheelite included in pyrite, and also surround, slightly embay and replace first-generation pyrite. Rutile appears to have replaced ilmenite along fractures (Fig. 2), and is found in complex intergrowths with ilmenite (Fig. 3). Based on geochemical and mineralogical evidence, the breakdown of primary magnetite and some ilmenite during pyritization appears to have liberated iron and titanium, which were consumed in the formation of pyrite, ankerite, ilmenite and rutile (Giddings 1986). The iron appears in the veins and zones of alteration as concentrations of ilmenite, ankerite and pyrite. The complex rutile–ilmenite grains, commonly found in close proximity to native gold (Fig. 3), appear to have formed as a result of oxidation of primary ilmenite,

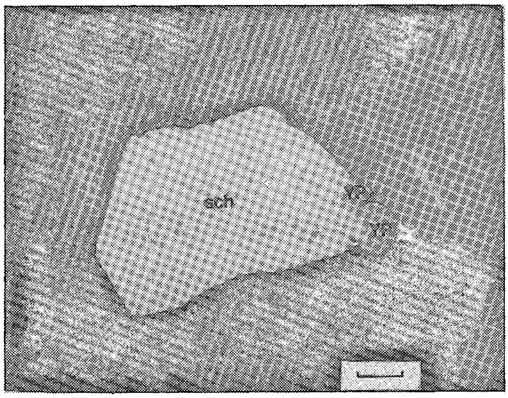

FIG. 2. Subhedral grain of scheelite (sch) in contact with xenotime (YP), rutile (ru) and ilmenite (il). Note rutile replacing ilmenite along fractures within the ilmenite. The dark surrounding areas are quartz, albite and carbonate gangue. Bar scale represents 10 μm.

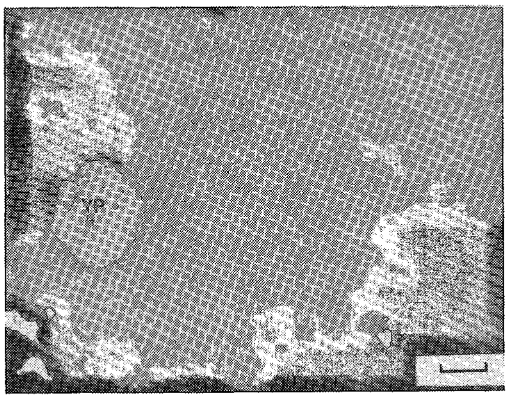

FIG. 3. Euhedral grain of xenotime (YP) partly enclosed in a complex intergrowth of ilmenite (light grey) and rutile (dark grey). Bright grain to the lower right is native gold, bright grains to the lower left are altaite, and darker areas are gangue. Bar scale represents 25 μm.

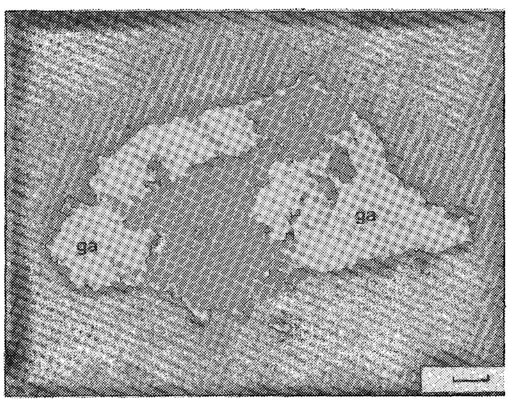

FIG. 4. Galena (ga) surrounding, embaying and replacing early-generation pyrite (py). The dark surrounding areas are quartz, albite and carbonate gangue. Bar scale represents 10 μm.

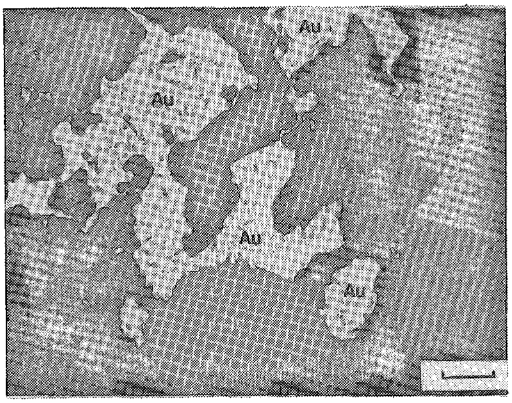

FIG. 5. Minor embayment and replacement of first-generation pyrite (py) by native gold (Au). Notice how the gold extends out into the surrounding gangue. Bar scale represents 50 μm.

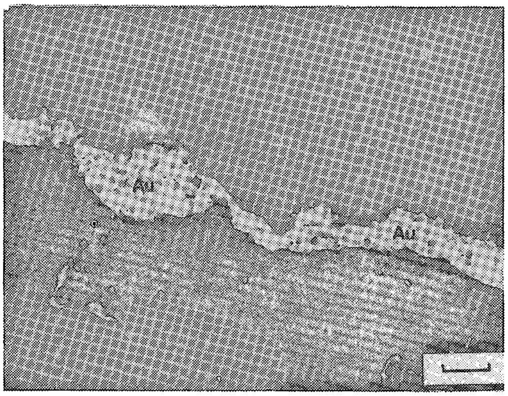

FIG. 6. Native gold (Au) concentrated to the outside and partly replacing second-generation pyrite (py). The darker areas are mainly quartz. Bright grains below the gold are altaite. Bar scale represents 25 μm.

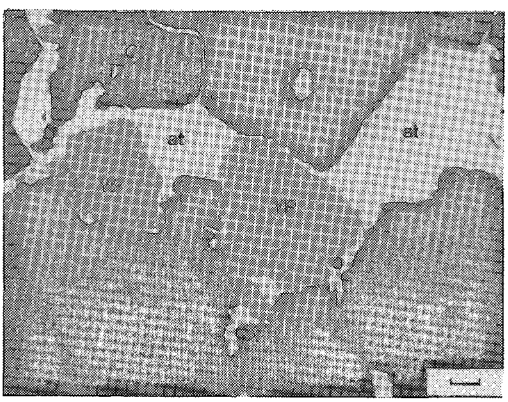

FIG. 7. Altaite (at) surrounding, embaying and replacing xenotime (YP). The dark surrounding areas are quartz, albite and carbonate gangue. Bar scale represents 10 μm.

similar to the processes documented by Haggerty (1976).

Intermediate-stage mineralization

The intermediate stage of mineralization predominantly involved sulfide minerals: sphalerite, chalcopyrite, galena and the second generation of pyrite. Minor sphalerite occurs as fine-grained aggregates concentrated adjacent to veins, and within veins. It is also found concentrated near the host-rock contact and interstitial to the albite, quartz and carbonate gangue of the visibly altered zones.

Chalcopyrite occurs as scattered, interstitial, anhedral grains in zones of visible alteration. Chalcopyrite exists in contact with, and as small inclusions in, both generations of pyrite.

Galena is present as a minor constituent in some gold-bearing assemblages. It is commonly found replacing anhedral, first-generation pyrite (Fig. 4), and included within and concentrated around first-generation pyrite with no apparent replacement. Remnant blebs of chalcopyrite in galena have been reported and are interpreted to represent almost complete replacement of chalcopyrite by galena (Webb 1948).

Euhedral to subhedral cubes of second-generation pyrite are found both in veins and in associated zones of alteration. These grains range in size from less than 1 mm up to 16 cm across. The highly fractured pyrite is commonly sealed with quartz and carbonate, and occasionally contains altaite and gold.

Late-stage gold and telluride mineralization

The final stage of mineralization resulted in intimate associations of native gold, petzite, altaite and calaverite. The crystallization of the second-generation pyrite appears to have continued during this stage. The development of exsolution grains of the tellurides and gold in second-generation pyrite and the replacement of second-generation pyrite by tellurides and gold indicate: 1) simultaneous crystallization of gold and the tellurides with second-generation pyrite, 2) termination of pyrite crystallization and mechanical fracturing, and 3) continued deposition of gold and tellurides in fractures, along cleavage planes, and along grain boundaries of pyrite.

Native gold occurs predominantly in the zones of visible alteration and is occasionally found within veins. The compositions of the native gold from Goldlund range from $Au_{88}Ag_{12}$ to $Au_{97}Ag_3$ (atom %). In the altered zones, native gold seals fractures in quartz, albite, ankerite and calcite. Gold was also observed in hand specimen as fracture fillings up to 0.2 cm wide in vein quartz.

Gold is closely associated with the tellurides and both generations of pyrite. The highest concentrations of gold are associated with the first generation of pyrite. Grains of irregularly shaped gold up to 300 μm in diameter are found in contact with and slightly replacing the pyrite (Fig. 5). Within the second generation of pyrite, gold occurs in irregular grains and in small, exsolved grains (<2 μm). Gold is also concentrated to the outside (Fig. 6), and fills fractures within the second-generation pyrite.

Petzite Ag_3AuTe_2 occurs within second-generation pyrite as irregular patches and round inclusions up to 40 μm across. It also occurs in composite grains, along with calaverite, altaite and native gold.

Altaite PbTe occurs within the altered host-rock and is commonly associated with native gold. It fills fractures in albite, quartz and other gangue minerals in these zones and occasionally fills fractures in vein quartz. In addition, it is commonly found interstitial to the gangue minerals of the host rock, as veinlets and discrete anhedral grains. The altaite may be found in direct contact with pyrite, ilmenite, rutile, apatite, monazite, xenotime, petzite, calaverite and native gold. In both generations of pyrite, the altaite is commonly concentrated on the outside of grains. It also occurs as round and irregular grains in second-generation pyrite, as fillings in fractures within this pyrite and in segregations and replacement veins. Altaite occasionally replaces early-formed minerals such as xenotime (Fig. 7).

Calaverite $AuTe_2$ occurs in various combinations with petzite, altaite and native gold in composite grains, and as irregular and occasionally round grains within second-generation pyrite. The composite grains are included in second-generation pyrite and also interstitial to the gangue minerals of the altered zones. Associations observed in the composite grains include calaverite - petzite - altaite - native gold (Fig. 8), calaverite - altaite and calaverite - petzite - altaite. Calaverite was also observed in anhedral grains within gangue near the composite telluride-gold grains (Fig. 8). Occasionally, inclusions of petzite, calaverite, and altaite within second-generation pyrite are sufficiently abundant to give the pyrite a mottled texture. The compositions of native gold, petzite, altaite and calaverite are given in Table 1.

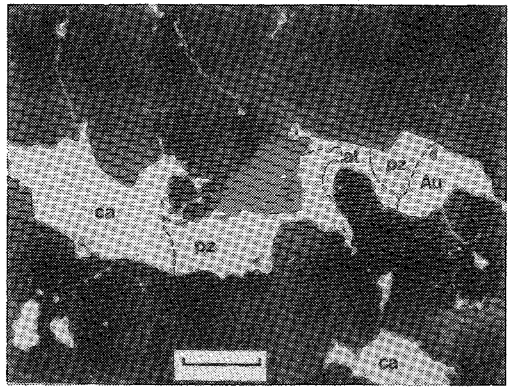

FIG. 8. Composite grain of native gold (Au), petzite (pz), altaite (at) and calaverite (ca). Notice how altaite cuts across petzite. Dark surrounding areas are gangue. Bright grains in gangue are predominantly altaite. Bar scale represents 50 μm.

DISCUSSION

The textural relationships between the various ore minerals at the Goldlund mine suggest a three-stage paragenetic sequence. Initial influx of ore-bearing solutions at elevated temperatures resulted in the crystallization of first-generation pyrite, scheelite, and xenotime, the breakdown of magnetite and ilmenite and the redistribution of iron and titanium. Increased concentrations in the host rock of sulfur, zinc, copper and lead near the veins (Giddings 1986) indicate that at lower temperatures, the influx of sulfur-, zinc-, copper-, and lead-bearing fluids resulted in the formation of sphalerite, chalcopyrite and galena. Iron released by the decomposition of iron oxides and silicates continued to combine with sulfur to form cubes of second-generation pyrite. The introduction of gold, silver and tellurium, and continued introduction of lead at lower temperatures, resulted in the formation of native gold, calaverite, petzite, and altaite late in the paragenetic sequence. The small amount of sulfur introduced at this time went into the continued formation of second-generation pyrite. Galena formed early at high temperatures, at a stage when sulfur was actively added to the rock by ore-bearing solutions. Late in the paragenetic sequence, lead combined with tellurium to form altaite instead of galena.

Pyrite played an important role in the concentration and crystallization of gold at the Goldlund mine. In a manner similar to that suggested by Boyle (1979), the second-generation pyrite appears to have taken in gold and silver in solid solution and as layers on the growing faces of the crystals. Migration of gold, by diffusion, to sites of low chemical potential, such as fractures and grain boundaries, may

TABLE 1. COMPOSITIONAL RANGE OF NATIVE GOLD, PETZITE, ALTAITE AND CALAVERITE

		1.	2.	3.	4.
Au	wt.%	88.51-95.43	22.63-24.03	0.00- 0.22	41.97-42.57
Ag		5.13- 6.92	42.52-44.73	0.65- 1.28	0.30- 0.56
Te		0.00- 0.33	29.56-31.37	37.25-37.90	55.61-57.16
Pb		0.00- 0.00	0.15- 0.88	60.58-61.73	0.00- 0.45

1. Range of 4 samples of native gold from this study.
2. Range of 4 samples of petzite from this study.
3. Range of 3 samples of altaite from this study.
4. Range of 4 samples of calaverite from this study.

explain the concentration of gold in these positions in association with second-generation pyrite. Small, round exsolution-blebs of native gold, petzite and calaverite within second-generation pyrite also support the syngenetic relationship between gold and the second-generation pyrite.

The interaction of gold-bearing fluids with pre-existing pyrite appears to have resulted in the precipitation of gold in association with both first-generation, anhedral pyrite and second-generation pyrite. This process was suggested by Colvine *et al.* (1984) to explain the common association of native gold and sulfides, in particular pyrite, in numerous gold deposits. At Goldlund the concentrations of gold are usually peripheral to the pyrite grains and may extend out into the surrounding gangue (Fig. 5), with the principal sites of gold mineralization having been the pre-existing grains of hydrothermal pyrite.

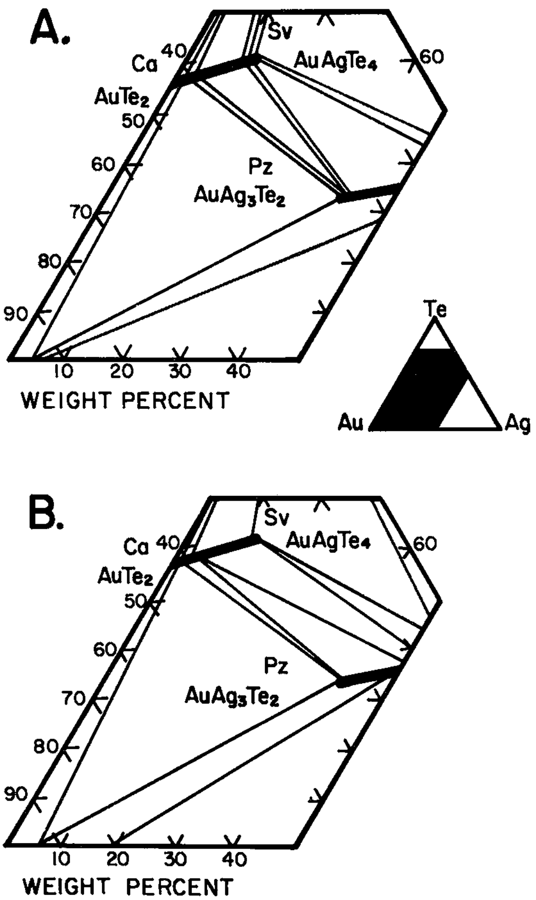

FIG. 9. Relationships in the synthetic Au–Ag–Te system. A represents the 300°C isotherm from Markham (1960), whereas B represents the 290°C isotherm from Cabri (1965). Abbreviations: (Ca) calaverite, (Sv) sylvanite, and (Pz) petzite.

The fine details of the phase relations involving transition-metal tellurides have not been completely worked out. Kelly & Essene (1982) and Afifi, Kelly & Essene (in prep.) discussed some general aspects of the stability of binary telluride systems, but noted a lack of thermodynamic data for many tellurides and related phases.

Phase relations in the Au–Ag–Te system have been experimentally investigated by Markham (1960) and Cabri (1965). As depicted in Figure 9, the mineralization at Goldlund is consistent with the results of both studies. The absence of minerals such as hessite, stuetzite, sylvanite and krennerite at Goldlund is due to the high Au:Te and Au:Ag values in the ore.

The intimate association of gold, calaverite and petzite may be used to estimate the temperature at which the late-stage mineralization occurred. The three-phase asssemblage is stable over a fairly wide range of temperatures (Markham 1960, Cabri 1965). However, the composition of the Au-rich alloy varies with temperature. Markham (1960) noted the compatibility of petzite and calaverite with a gold-rich alloy of composition $Au_{89}Ag_{11}$ to $Au_{93}Ag_7$ (atom %) at 300°C. Gold samples analyzed from Goldlund range from $Au_{88}Ag_{12}$ to $Au_{97}Ag_3$, suggesting a temperature fairly close to 300°C for the deposition of petzite, calaverite and native gold.

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